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RESEARCH MEMORANDUM

for the

Office of Naval Research, Department of the Navy

HIGH-SPEED DRAG AND OPENING CHARACTERISTICS

OF A KAMAN ROTOCHUTE MODEL

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SUMMARY

An experimental investigation has been made in the Langley high-speed 7- by 10-foot tunnel in the Mach number range from 0.40 to 0.80 to determine the drag and opening characteristics of a model of a Kaman Aircraft Corporation Rotochute. The Rotochute, which is basically a two-bladed flapping rotor with governor-controlled blades designed for lowering cargo containers from high-speed aircraft, was tested at various Mach numbers simulating constant rates of descent. In these tests, the drag, rotational speed, and coning angle of the blades were determined. In some additional tests, in which the Rotochute was allowed to open at various airspeeds, time histories of the drag and rotational-speed variation from opening to equilibrium rotational speed were obtained. The tests were made at an angle of attack of 0° . Two sets of blades were tested: one having an NACA 0015 airfoil section and the other an NACA 0008 airfoil section. In order to expedite publishing of the data, no analysis is presented.

INTRODUCTION

At the request of the Office of Naval Research, Department of the Navy, a wind-tunnel investigation was made to determine the high-speed drag and opening characteristics of a model of the Kaman Aircraft Corporation Rotochute. The Rotochute (figs. 1 and 2) is an aerial vehicle designed for the delivery of M-2 cargo containers from aircraft in low-altitude high-speed ground-supply missions. The history and development of various models of the Rotochute are presented in reference 1. The results of an experimental investigation of one of these designs to determine the low-speed static aerodynamic and operational characteristics are presented in reference 2.

The present paper contains the results of tests at several Mach numbers to determine the drag and rotational speed of the Rotochute for steady-state conditions. This paper also includes time histories of the drag and rotor revolutions from opening of the Rotochute until a constant rotational speed was obtained. (This operation takes place in what amounts to a transient tunnel Mach number condition resulting from dynamic-pressure reductions of about 10 percent which occur when the Rotochute blades open.) A 16-mm-film record, from which the coning angles of the rotor were determined, was made of the rotor operations. The tests were made at an angle of attack of 0° through a Mach number range from 0.40 to 0.80.

SYMBOLS

The symbols used herein are standard NACA symbols. The drag was measured parallel to the wind axes.

S	disk area of rotor blades operating at zero cone angle, sq ft
D	drag, lb
ΔD	$= (D)_{\text{rotor attached}} - (D)_{\text{suspension system, including Rotochute body}}$
V	tunnel airspeed, ft/sec
V_t	rotor-blade tip speed, $R\Omega$, ft/sec
R	rotor radius, ft
Ω	rotor speed, radians/sec
α_0	cone angle, deg (see fig. 3)
ΔC_D	incremental drag coefficient, $\Delta D/qS$
t	time after release of rotor, sec
M	Mach number
q	dynamic pressure, $\rho V^2/2$, lb/sq ft
ρ	mass density of the air, slugs/cu ft
N	revolutions

OPERATION

A brief description of the use and the operation of the Rotochute is given herein. The purpose of the Rotochute is the delivery of M-2 supply containers in low-altitude high-speed ground-supply missions. This will involve decelerating missiles weighing up to 650 pounds from forward velocities of approximately 1,000 feet per second ($M = 0.90$) to descent velocities at touchdown of about 25 feet per second in less than 500 feet vertical distance. This operation is accomplished by a two-bladed flapping rotor synchronized in coning by means of suitable linkages. The blade pitch angle is regulated by a governor to prevent the rotor overspeeding.

In practice, the Rotochute is carried aboard an aircraft either internally or externally with the blades folded back for compactness. A static line attached to the Rotochute releases a mechanism which allows the blades to pivot about the blade-sweep hinge with the tips moving in the direction of rotation. The relative angle of the blades to the airstream sets up aerodynamic forces which start rotation. The centrifugal forces on the blades force the tips away from the axis of rotation. An equilibrium rotational speed and coning angle which depend largely upon the aerodynamic drag and the centrifugal forces are quickly obtained.

MODEL AND APPARATUS

The Rotochute model which was supplied by the Kaman Aircraft Corporation consisted of a rotor and body as shown in figure 1. The blades of the rotor are mounted on the hub at the blade pitch hinge. The blade pitch-control spring holds the blades against a stop in the static condition of about 10° nose down, when referred to a normal attitude. A means of adjusting the spring tension and the stop are provided. The blades are also attached at the blade coning hinge, allowing the blades to fold back in a plane parallel to the airstream (fig. 1(b)). The blades are held in a fully extended position when inoperative by the blade support arm and the tendency of the blade sweep spring to rotate the rear-bearing housing. A mechanism is also provided for changing the blade sweep angle which consists of a blade sweep spring, sliding collar, blade sweep-control arm, and the blade sweep hinge. For the rotor release tests (opening), a block was placed between the hub plate and sliding collar for compressing the sweep spring. When operation was desired, the sweep mechanism and rotor lock, which was provided for the rotor as an assurance against turning prematurely, were released from outside of the tunnel through cables attached to the block and locking pin. (It should be noted here that when the blades are rotated forward about their coning hinge

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axis, the 10° sweep results in an angle-of-attack change of approximately 10° when the blades are fully extended.)

The model suspension system is shown in figure 2 and schematically in figure 3. In these tests, the body, which served as a part of the suspension system, was mounted on a 2-inch-diameter pipe which in turn was supported from the tunnel walls by two sets of diagonally opposed cables. The system was restrained in drag by a diagonal cable. From the geometry of the system (fig. 3), it can be seen that the load in the vertical load cable was approximately equal to the drag of the system, and this was determined from the load cell which had been calibrated as mounted by applying a force in the drag direction. The drag data from the Rotochute opening tests were measured on a recording oscillograph while that of the steady-state tests were measured by use of a potentiometer. The rotational speed of the rotor was measured on a recording oscillograph from an electrical tachometer made up of a magnet and coil mounted on the rotor and body, respectively.

Two sets of blades were tested in this investigation: one having an NACA 0015 section and the other an NACA 0008 section. The blades had a constant chord with circular tips. Other physical characteristics of the blade are given in the following table:

NACA blade section	Chord, ft	Diameter, ft	Blade length including root, ft	Disk area, S, sq ft
0015	0.297	4.029	1.714	12.76
0008	.250	3.935	1.667	12.15

No attempt was made to measure the preload on the governor springs. The preload was less for the NACA 0008 blades than for the NACA 0015 blades. However, the governing spring constant was the same for both sets of blades.

TESTS

Three types of tests were made to determine the high-speed drag and opening characteristics of the Rotochute. The first tests were made to determine the drag of the support system (tare drag) inasmuch as the drag measured in the steady-state and opening tests which followed was a combination of the drag of the rotor and the support system. The steady-state tests were made with the rotor autorotating at constant

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Mach numbers during which the drag and rotational speed were recorded. The opening tests of the Rotochute were made at preset tunnel Mach number to determine the rotor drag and rotational-speed variation with time from a point just prior to release until an equilibrium rotational speed was obtained. (In these tests, the rotor blades assumed an attitude prior to release similar to that shown in fig. 1(b)). Motion pictures were taken at approximately 60 frames per second of all tests with the rotor operating except the steady-state tests of the NACA 0008 blades.

PRESENTATION OF DATA

Figure 4 is a typical oscillograph record of the operation of the rotor following release at a preset tunnel Mach number. Figures 5 and 6 show the variation of the incremental drag and revolutions of the rotor from time of release until a steady-state condition was obtained. The incremental drag, in pounds, is presented in lieu of incremental drag coefficient because of the change in dynamic pressure occurring during the opening operation. The results of tests to determine drag, rotor tip velocity, and coning angle for the steady-state conditions are given in figure 7. The Mach numbers at which the coning angles are given for NACA 0008 blades were not measured for equilibrium conditions as motion pictures were not available for this configuration. They were measured, however, from motion pictures of the openings at a time when the drag values were at their maximum as shown in figure 6(a). Inasmuch as the maximum values of the drag at this time are approximately equal to the steady-state values (table I), it is thought that the error in Mach number may be relatively small.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 28, 1954.

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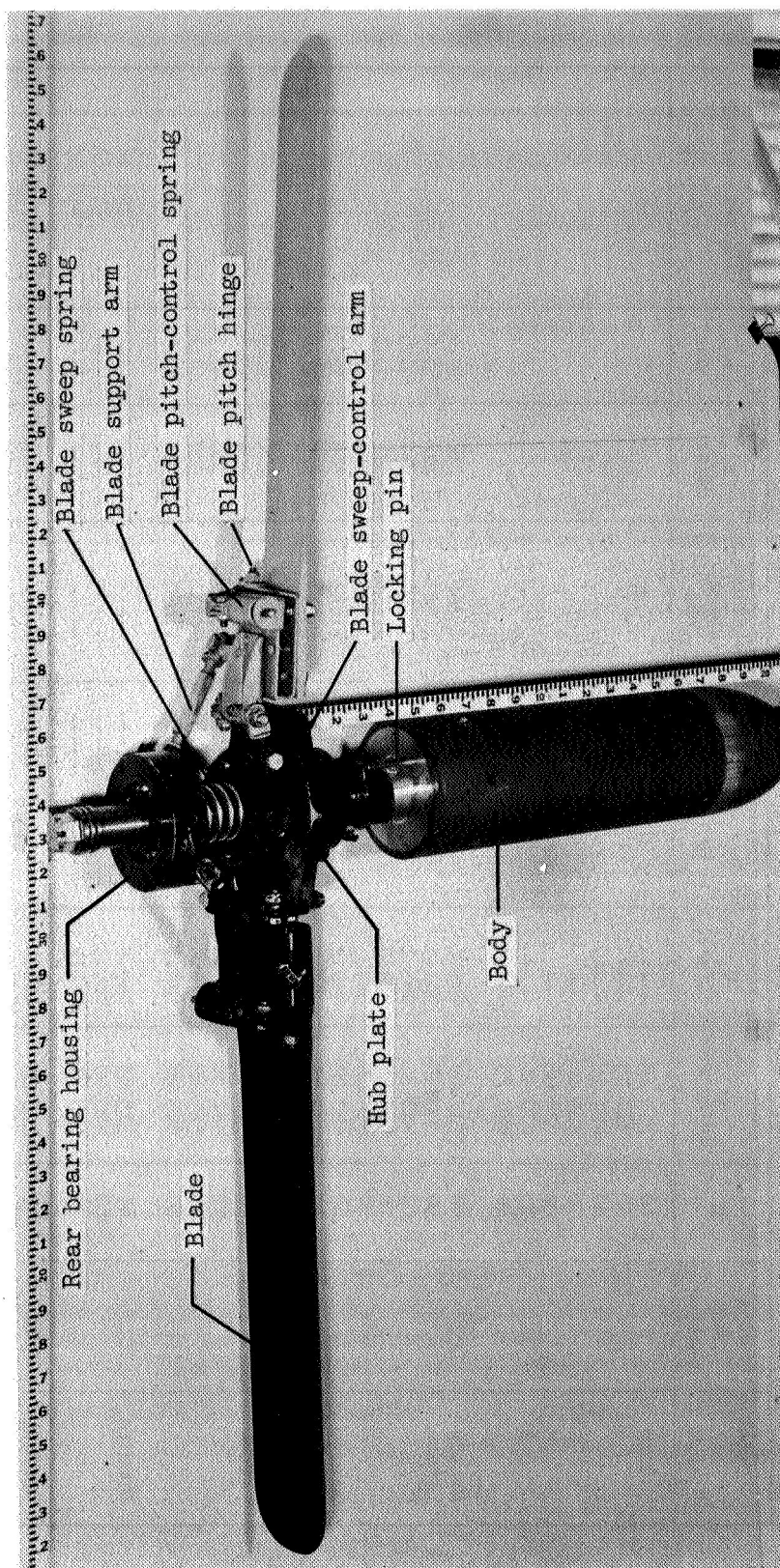
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REFERENCES

1. Tedeschi, L. J., and Robinson, D. W.: Preliminary Report of Rotochute Development. Rep. No. R-29 (Contract No. Nonr 901 (00)), Kaman Aircraft Corp.; Oct. 15, 1953.
2. Queijo, M. J.: Wind-Tunnel Investigation at Low Speed of the Static Aerodynamic and Operational Characteristics of a Model of the Kaman Rotochute. NACA RM SL54D13a, Office Naval Res., 1954.

TABLE I
AERODYNAMIC CHARACTERISTICS OF KAMAN ROTOCUUTE MODEL
TESTED IN LANGLEY HIGH-SPEED 7- BY 10-FOOT TUNNEL

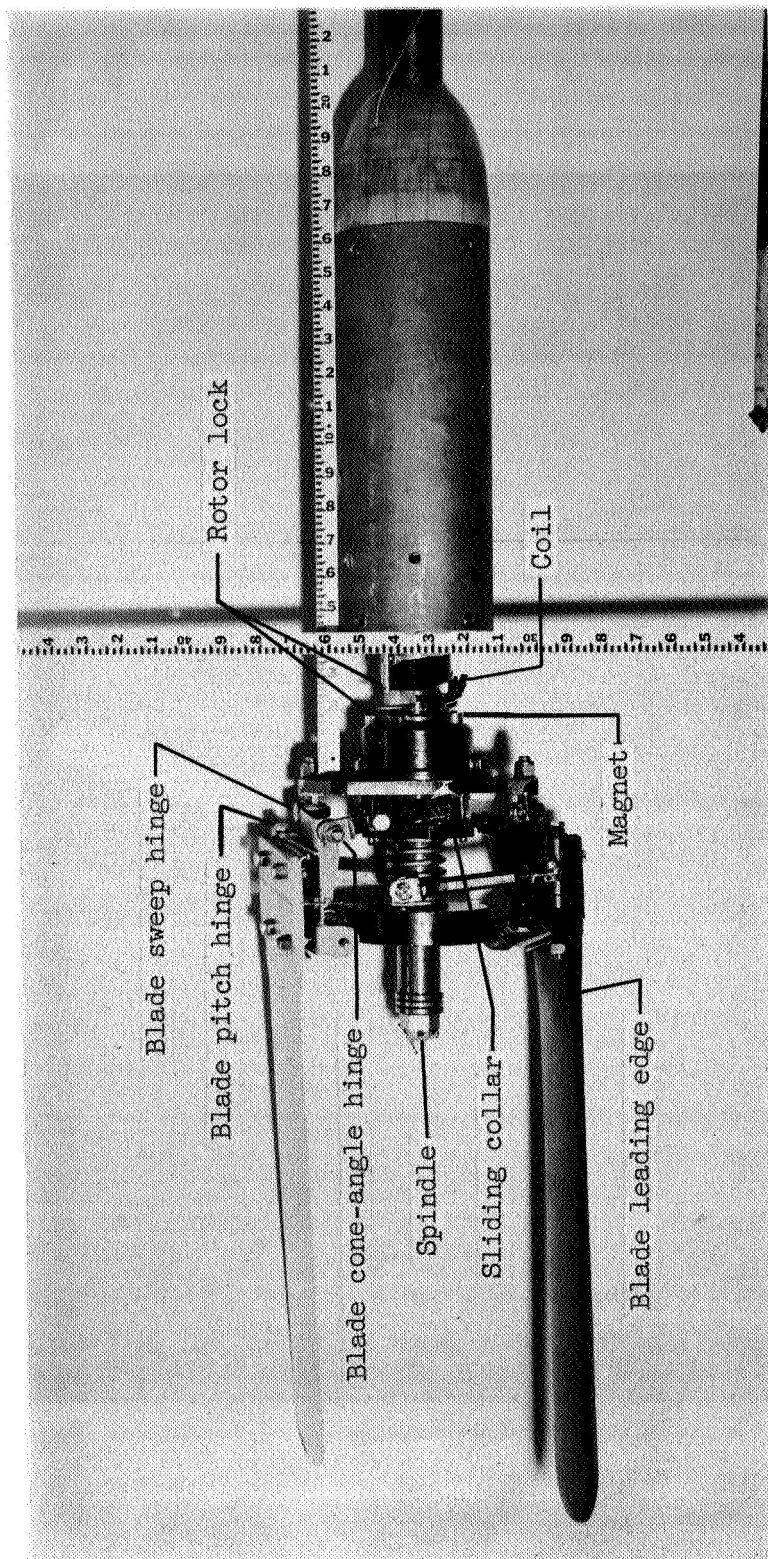
Type of test	NACA blade section	M	q , lb/sq ft	V , ft/sec	D, lb	ΔC_D	Rotational speed, rpm	V_t , ft/sec	α_0 , deg	(q) after opening, lb/sq ft
Tare		0.40	213.68	---	97					
		.50	312.95	---	147					
		.60	421.18	---	207					
		.70	525.64	---	262					
		.80	625.08	---	322					
		.85	670.16	---	382					
Steady state	0015	.86	679.73	---	407					
		.40	211.69	441.6	437	0.1259	1,368	288	27.4	
		.50	309.05	551.5	607	.1166	1,500	316	30.6	
		.60	416.84	663.1	792	.1100	1,646	347	31.5	
		.70	525.64	784.8	1,017	.1126	1,771	374	35.5	
		.77	595.05	859.0	1,147	.1116	1,870	394	37.0	
		.60	420.90	679.2	803	.1120	1,632	344	32.7	
		.40	213.53	454.4	430	.1222	1,318	278	27.8	
		.40	213.68	445.6	362	.1021	1,353	278	35.9	
		.50	312.95	554.0	491	.0905	1,477	304	40.6	
Opening	0008	.60	421.32	667.0	631	.0828	1,605	330	45.3	
		.70	525.82	775.6	764	.0786	1,737	357	49.2	
		.80	625.28	876.7	862	.0711	1,800	370	52.0	
		.40	213.53	449.9	---	---	---	---	---	191.16
Opening	0015	.60	420.90	666.3	---	---	---	---	---	377.64
		.70	525.64	771.1	---	---	---	---	---	457.63
		.40	213.39	451.0	---	---	---	---	---	196.45
		.60	420.90	671.1	---	---	---	---	---	387.31
Opening	0008	.80	625.28	882.2	---	---	---	---	---	574.19



L-84229.1

(a) Blades extended.

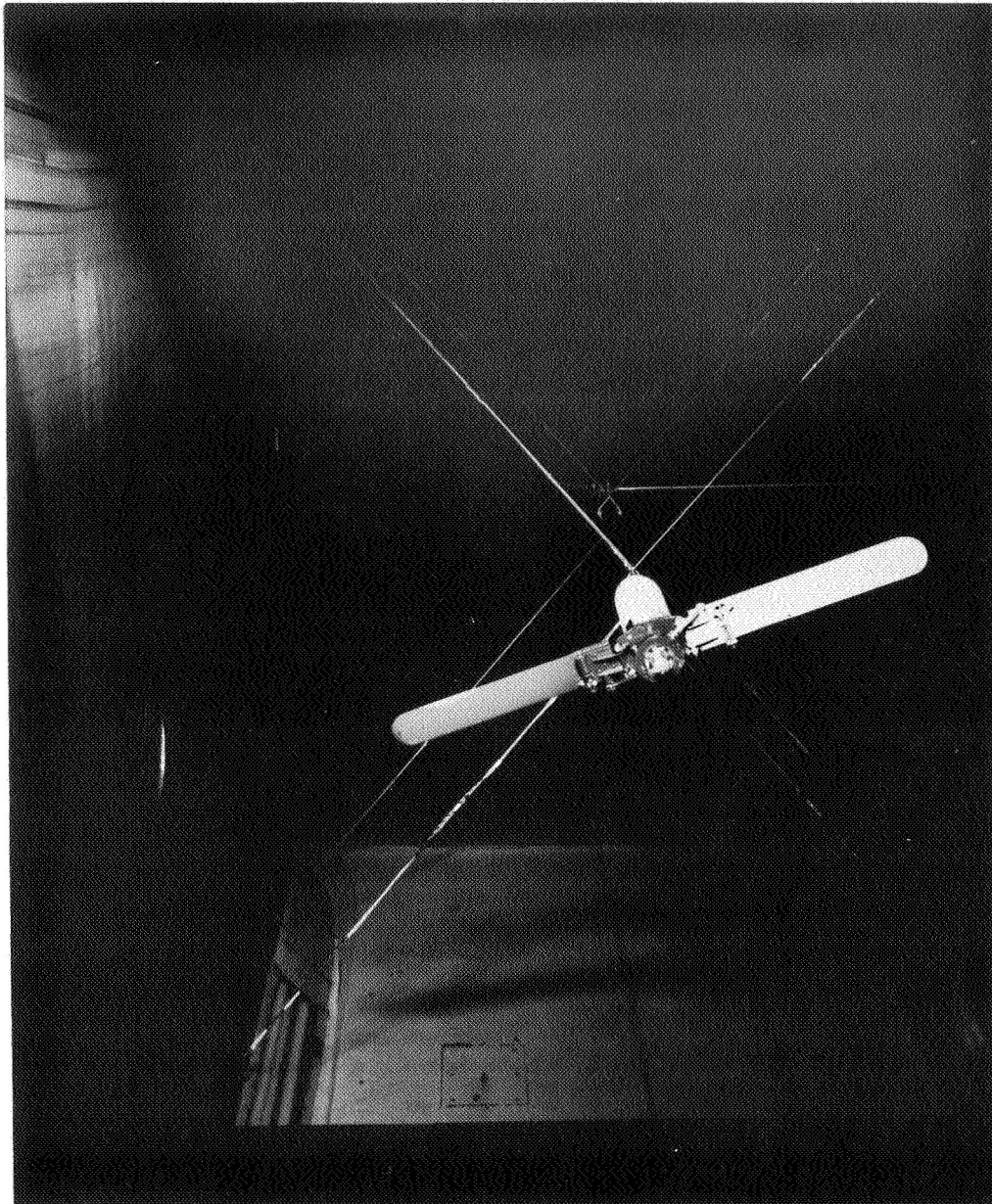
Figure 1.-- Details of the Kaman Rotocraft tested in the Langley high-speed 7- by 10-foot tunnel.



L-84230.1

(b) Blades folded back.

Figure 1.- Concluded.



L-84169

Figure 2.- Model of a Kaman Rotachute mounted in the Langley high-speed
7- by 10-foot tunnel.

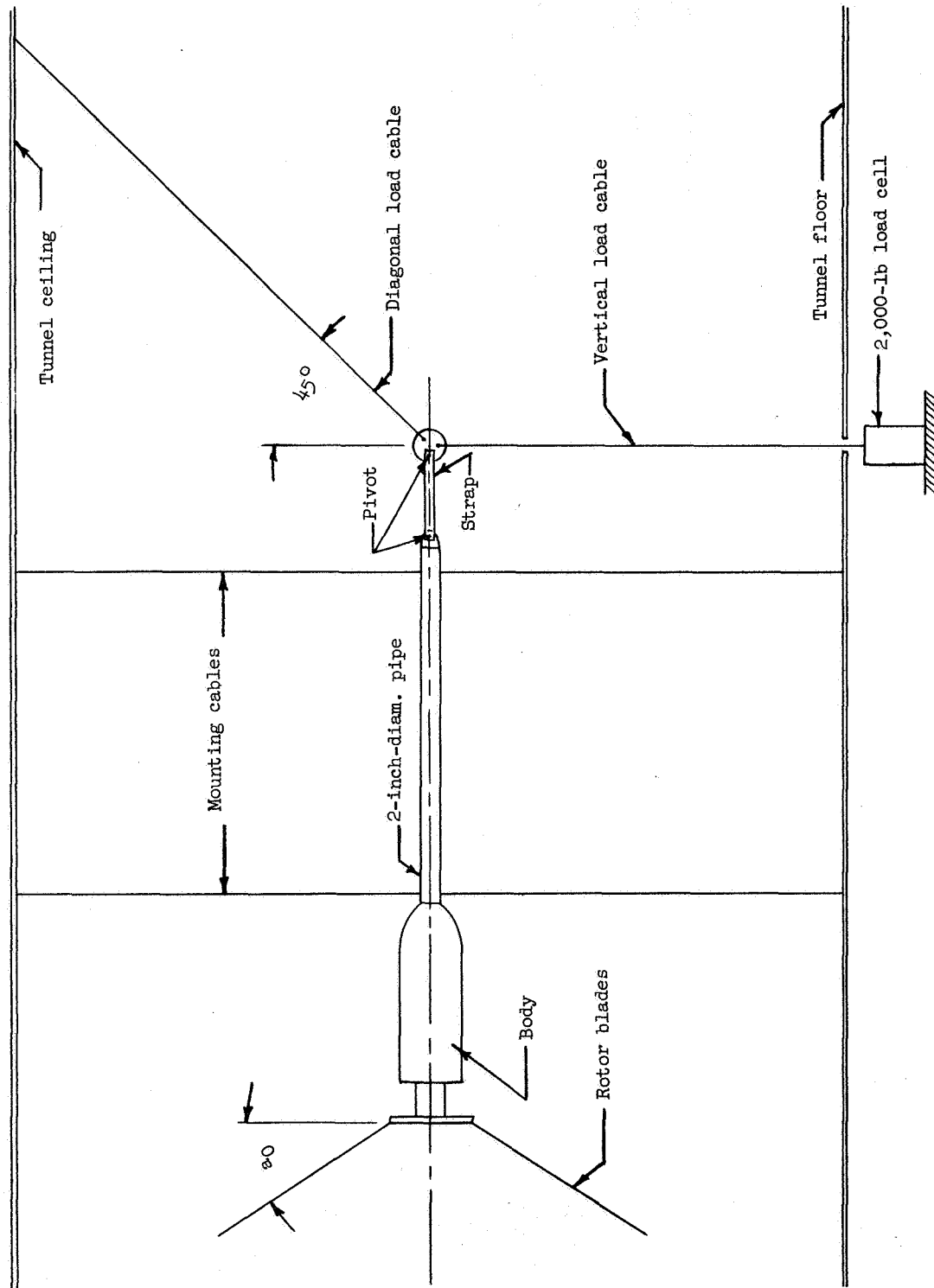


Figure 3.- Sketch of tunnel mounting system.

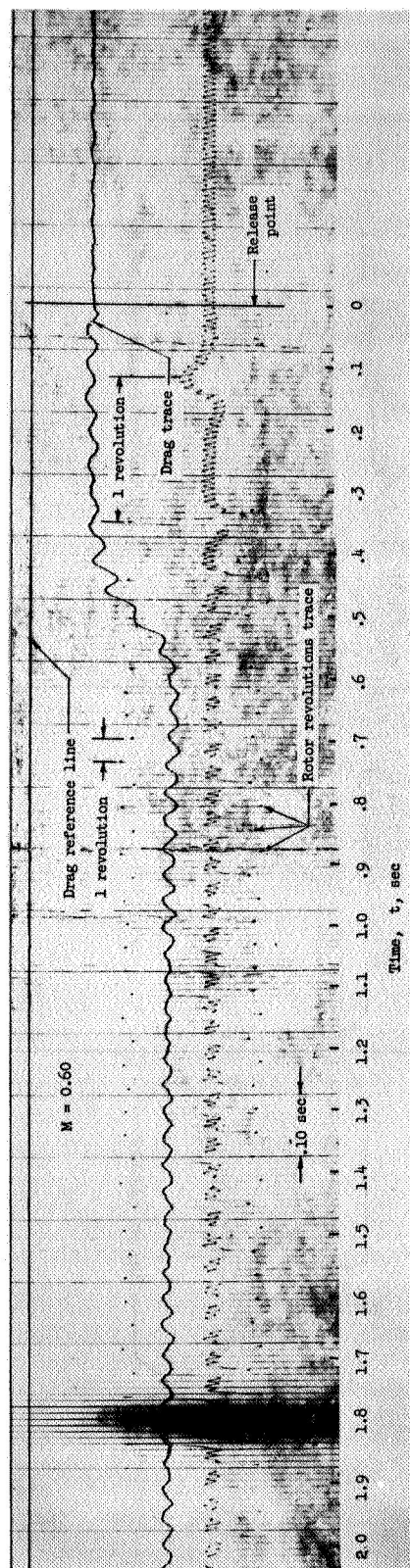


Figure 4.- Typical record taken on release of the Rotochute with the NACA 0008 blades.

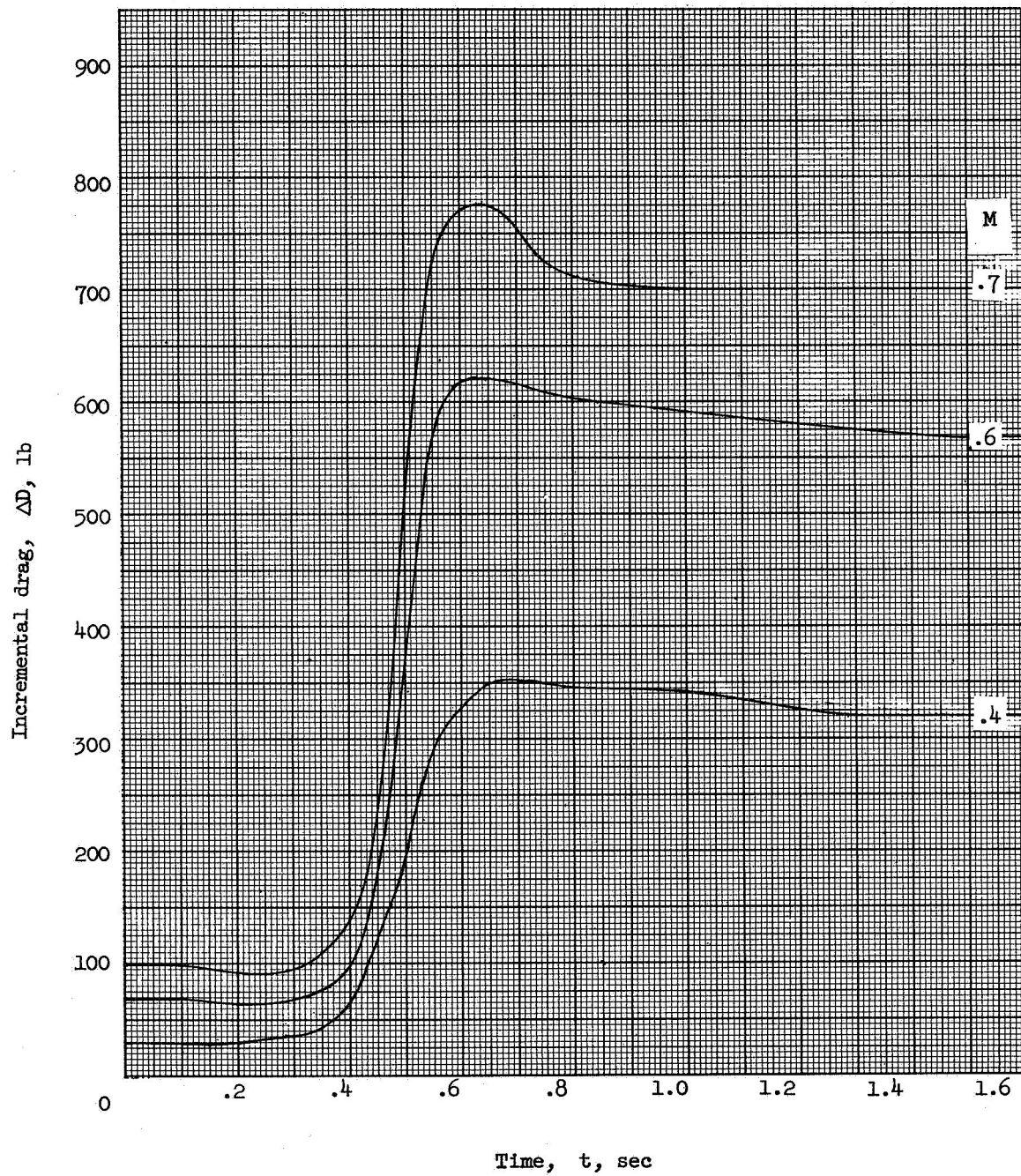
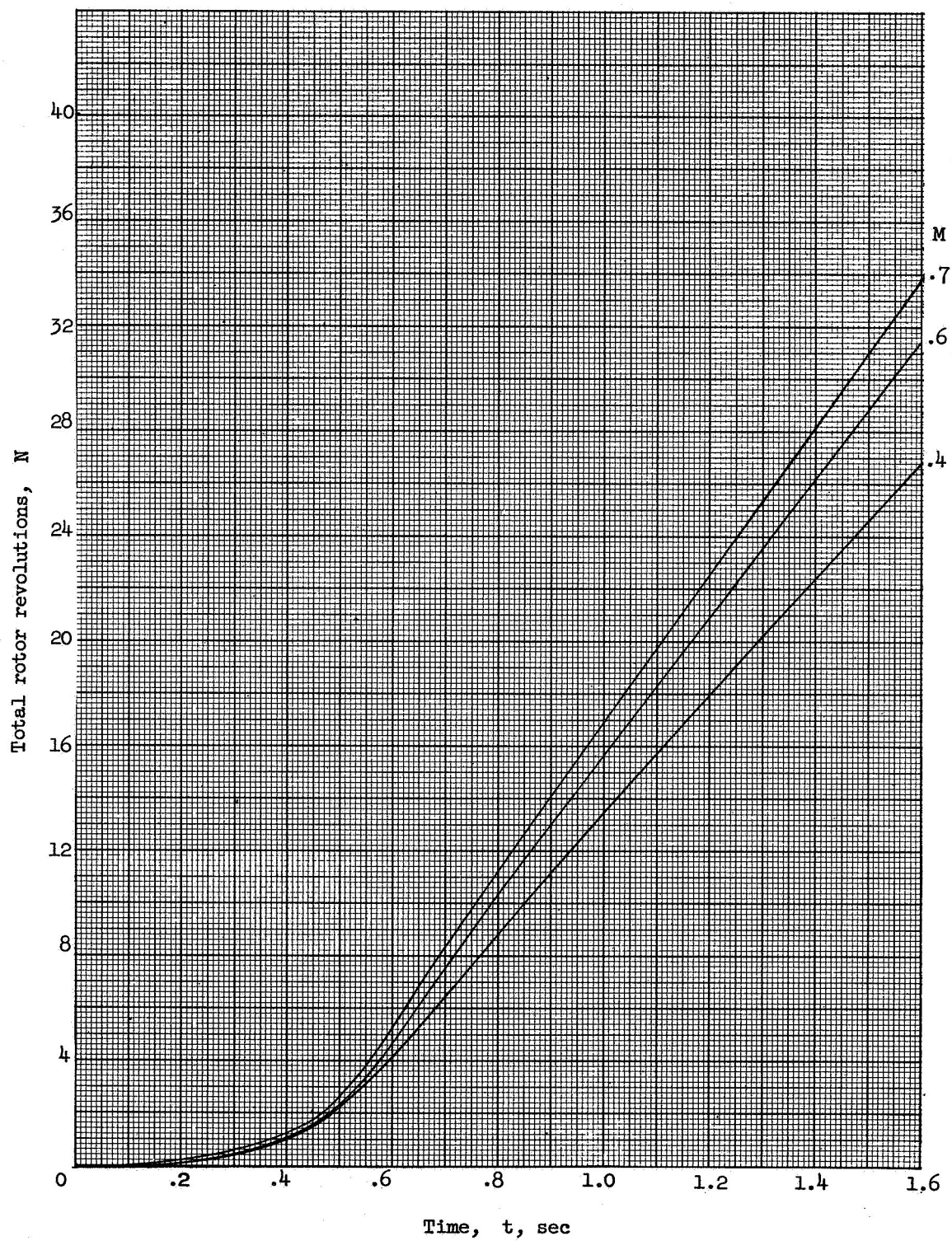
(a) ΔD against t .

Figure 5.- Effect of the Mach number on the opening characteristics of the rotor with NACA 0015 blade sections.



(b) N against t .

Figure 5.- Concluded.

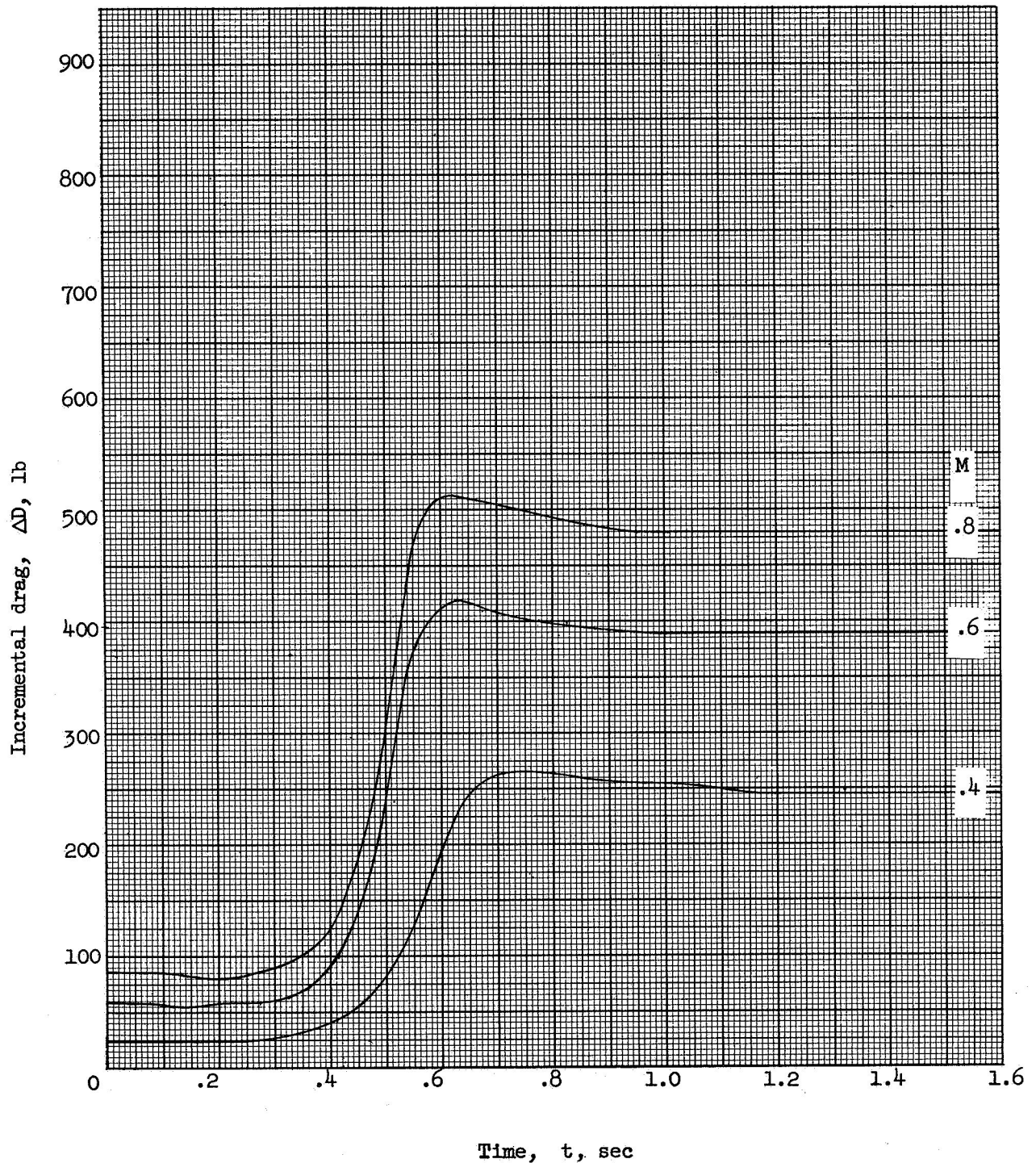
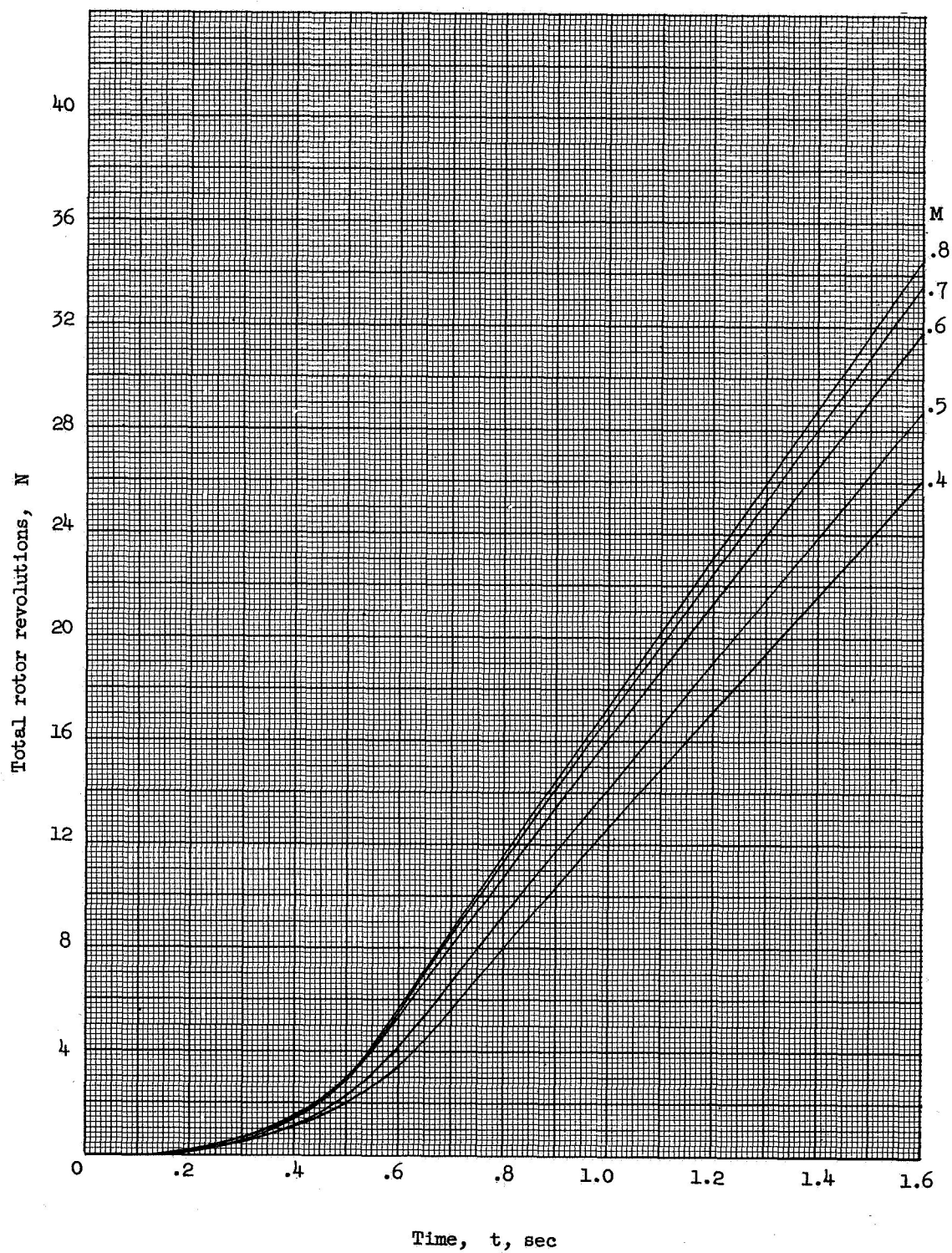
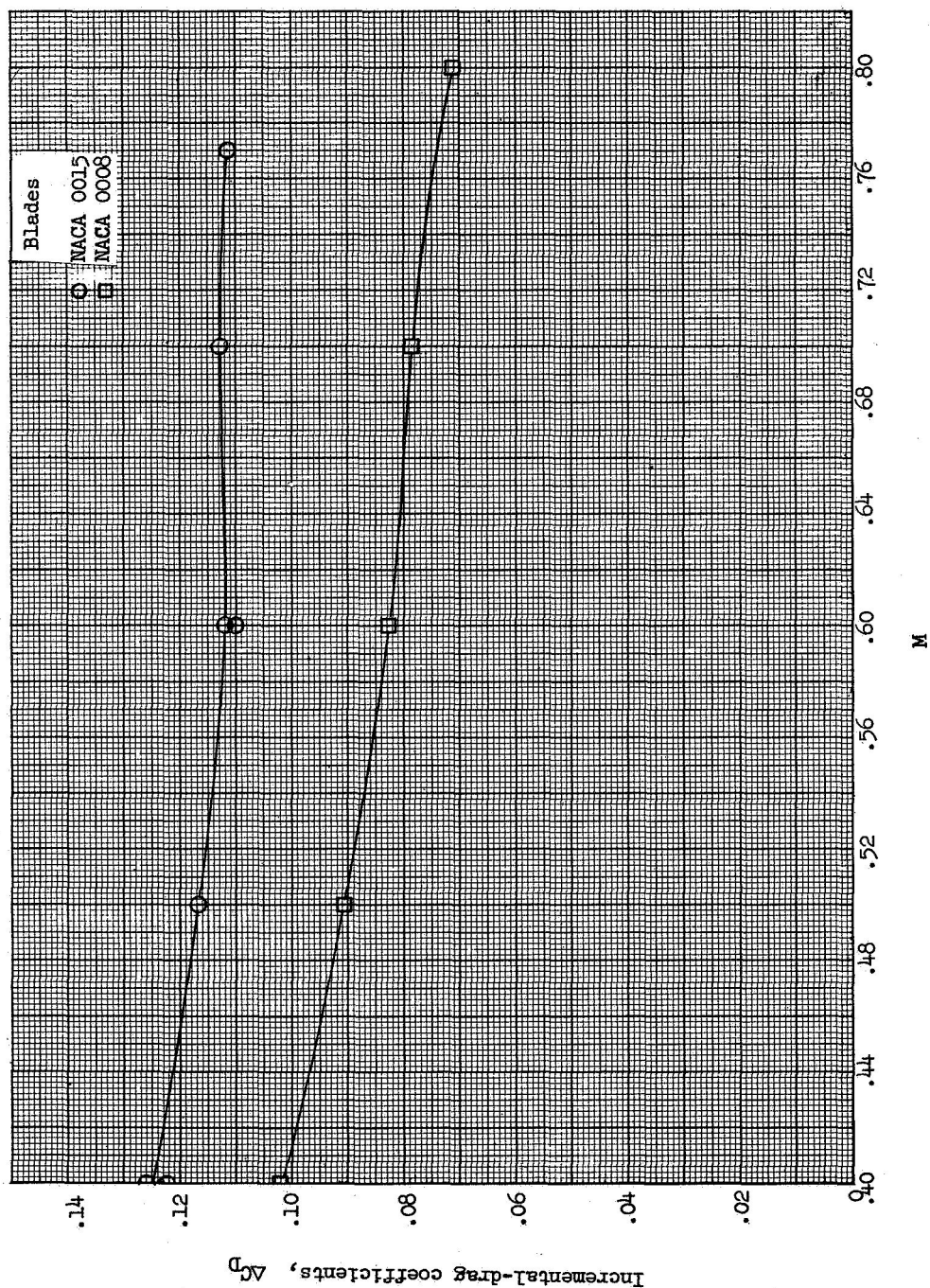
(a) ΔD against t .

Figure 6.- Effect of Mach number on the opening characteristics of the rotor with the NACA 0008 blade sections.



(b) N against t .

Figure 6.- Concluded.



(a) ΔC_D against M.

Figure 7.- Comparison of the governing characteristics of different rotor blades on a model of the Kaman Rotochute.

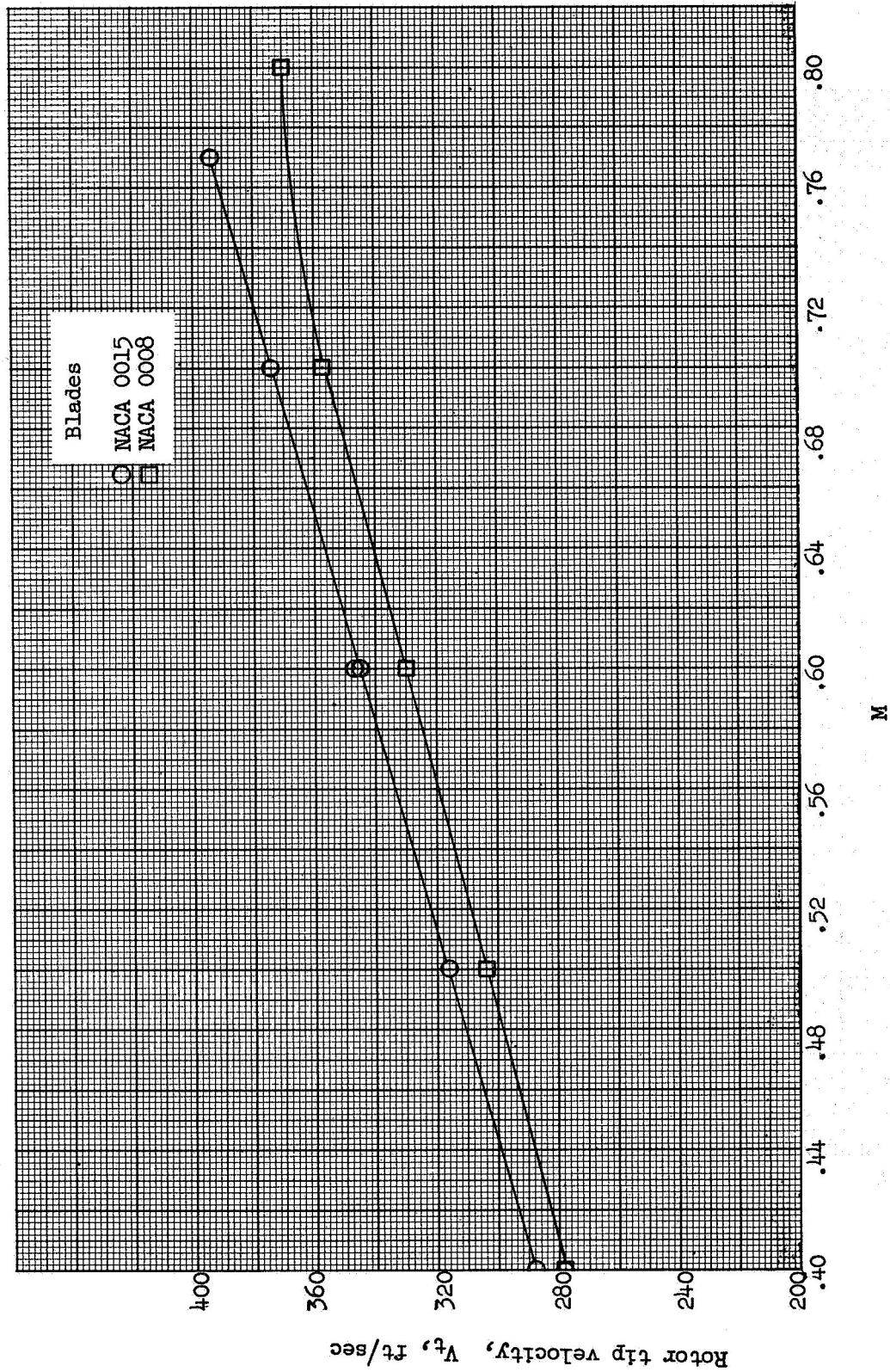
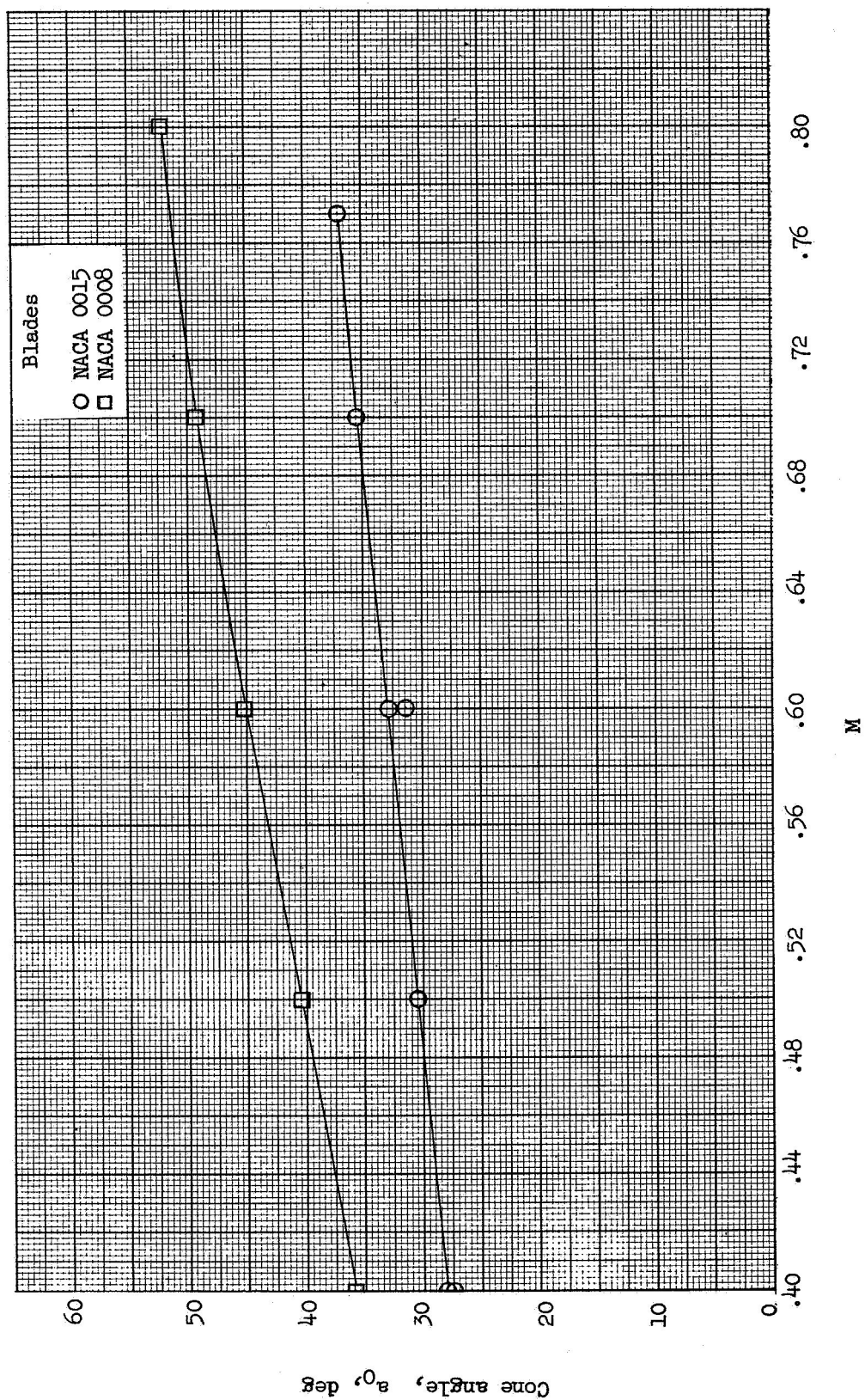
(b) V_t against M .

Figure 7.- Continued.



(c) α_0 against M .

Figure 7.- Concluded.